Areeb Shah Mohammed

Doctoral Student (Mathematics)

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Writing

Publications

Hidden Markov Models and the Bayes Filter in Categorical Probability — *IEEE Transactions on Information Theory*

Joint work with Tobias Fritz, Andreas Klingler, Drew McNeely, and Yuwen Wang — *1st July 2025*

- We characterize hidden Markov models in terms of conditional independence and algorithms for Bayesian filtering and smoothing in Markov categories with conditionals.
- We show that these algorithms specialize to existing ones such as the Kalman filter, forward-backward algorithm, and the Rauch-Tung-Striebel smoother.
- We also prove that the sequence of outputs of the Bayes filter is itself a Markov chain.
- `DOI:` 10.1109/TIT.2025.3584695, `arXiv:` 2401.14669

Preprints

Partializations of Markov categories — *arXiv*

5th September 2025

- We show that positive quasi-Markov categories are restriction categories, and thus serve a framework for categories of partial stochastic maps.
- We introduce a construction of a class of such categories called partialization, and prove that various desirable properties transfer from a Markov category to its partialization.
- We additionally introduce a new notion of Kolmogorov product suitable for such categories.
- `arXiv:` 2509.05094

Empirical Measures and Strong Laws of Large Numbers in Categorical Probability — *arXiv*

Joint work with Tobias Fritz, Tomáš Gonda, Antonio Lorenzin, and Paolo Perrone — *27th March 2025*

- We introduce the notion of quasi-Markov categories, which are intuitively categories of partially defined stochastic maps.
- We axiomatize the notion of empirical sampling within particular such categories.
- Given this, we prove a generalized version of the Glivenko-Cantelli theorem.
- `arXiv:` 2503.21576

Master Thesis

On a characterization of Higher Semiadditivity — *Universität Regensburg*

Under the supervision of Prof. Dr. Denis-Charles Cisinski — *2022*

- Hopkins and Lurie introduced a notion of m-semiadditivity for $m \geq -2$.
- Harpaz proves a universal property of the infinity category of spans of n-finite spaces with m-truncated wrong way maps which gives an alternate characterization of m-semiadditivity.
- We survey this sequence of results, providing a contiguous narrative with fewer changes of models.
- `URL:` https://www.areebsm.in/publications#asm2022masterarbeit

Expository

The Freyd-Heller group and the failure of Brown Representability — *The University of Chicago*

The University of Chicago Mathematics REU — *Summer 2019*

- The classical Brown repreesntability theorem applies to connected based spaces.
- We describe a the "Freyd-Heller" group, that results in a counterexample to both weakenings.
- URL: http://math.uchicago.edu/~may/REU2019/REUPapers/Areeb.pdf

Talks

International Category Theory conference 2025 — *Masaryk University, Czech Republic*

Partializations of Markov Categories — *17th July 2025*

Delivered a talk on partializable Markov categories and their applications to categorical probability and restriction category theory.

Applied Category Theory 2025 — *University of Florida*

Partializations of Markov Categories — *4th June 2025*

Delivered a talk on a formulation of a category of partial stochastic maps particularly suitable for categorical probability.

Seminar Talk

Chennai Mathematical Institute

Bayesian filtering and Smoothing in Markov categories — *27th February 2025*

Delivered a talk on recent work formulating Bayesian filtering, smoothing and associated algorithms in Markov categories.

Applied Category Theory 2023

University of Maryland

Hidden Markov Models and the Bayes Filter in Categorical Probability — *1st August 2023*

Delivered a talk on formulating hidden Markov models and Bayesian filtering in Markov categories.

URL: https://www.youtube.com/watch?v=PwI3oOXWWe8

Experience

Researcher

Universität Innsbruck

Research Employee at the Department of Mathematics — *2022–Present*

- Employed as a researcher in the Algebra group of the Department of Mathematics.
- Worked on the topic of Markov categories and their applications as part of the FWF Project 35992-N.

Teaching Assistant

National Programme on Technology Enhanced Learning, India

Teaching Assistant for the undergraduate Group Theory course at the National Programme on Technology Enhanced Learning — *Summer 2020*

- Responsibilities included checking exercise sheets and moderating the course forum, in particular answering student questions.

Teaching Assistant

Chennai Mathematical Institute

Teaching Assistant for the undergraduate Topology course at the Chennai Mathematical Institute — *Winter Semester 2019–20*

- Responsibilities included grading exercise sheets and conducting weekly tutorial sessions, as well as teaching when the instructor was unavailable.

Student Mentor

Chennai Mathematical Institute

Student mentor at the Chennai Mathematical Institute — *Academic Year 2019–20*

- Responsibilities included conducting weekly counseling sessions for first year students.

Talk Host

Chennai Mathematical Institute

Hosted a talk by Prof. Daniel Litt — *2020*

- Hosted a talk by Prof. Daniel Litt as part of the STEMS program at the Chennai Mathematical Institute.

Workshop on Seshadri Constants

National Institute of Science, Education, and Research, Bhubhaneshwar

National Centre for Mathematics Advanced Training in Mathematics Schools — *December 2019*

- Participated in workshop involving a series of talks by various speakers on topics related to Seshadri Constants.

The University of Chicago Mathematics REU

The University of Chicago

Faculty Mentor: Prof. Peter May — *Summer 2019*

- Wrote an expository paper on the failure of the Brown Representability Theorem in both the Homotopy category of unbased, connected CW complexes and the Homotopy category of based CW complexes.
- Participated in lecture series on various topics by the University of Chicago faculty.

Summer Internship in Algebraic Combinatorics

Indian Institute of Technology Madras

Mentor: Prof. Narayanan N — *Summer 2018*

- Completed a project under Professor Narayanan N of the Indian Institute of Technology, Madras on the topic of Algebraic Combinatorics, the application of algebraic methods to solving problems in combinatorics.

Asian Science Camp 2018

Manado, Indonesia

Participant — *Summer 2018*

- Was one of 20 selected to represent India at the Twelfth Asian Science Camp 2018, where we were given the opportunity to interact with leading experts in the field of research, including some Nobel Prize winners such as Prof. Takaaki Kajita of the University of Tokyo.
- Completed a group project involving a presentation at the camp.

Technical Internship

Ducima Analytics

Statistics and Data Analysis Intern — *Summer 2018*

- Performed statistical analysis of advertising revenue with the goal of optimizing the response to cost ratio of internet search advertisements.
- Preprocessed data, removed outliers, performed statistical tests and designed a regression model.
- Prepared a presentation for the clients.

Vijyoshi National Science Camp

Indian Institute of Science

Participant

2016

- Attended lectures by various distinguished professors and multiple lab visits.

Research Science Initiative – Chennai Summer Programme

Indian Institute of Technology, Madras

Intern

Summer 2016

- Attended daily lectures on various topics by the IIT Madras faculty, and visits to other labs and research facilities in and outside IIT Madras.
- Completed a project under the direct supervision of Professor Tripathy of the IIT Madras theoretical physics department.
- Analyzed dynamical systems via phase portraits and classified the nature of singularities to make local predictions.
- Delivered a presentation on the topic.

Education

Universität Innsbruck

Innsbruck, Austria

PhD in Mathematics

2022–Present

- PhD study on the topic of Markov categories and their applications under the supervision of Dr. Tobias Fritz.
- Produced research on various related topics, including Hidden Markov models, Bayesian filtering, smoothing, empirical measures, and laws of large numbers.

Universität Regensburg

Regensburg, Germany

M.Sc. Mathematik

2020–2022

- Took courses in various fields of mathematics, focusing on category theory, homotopy theory, logic, and algebraic geometry.
- Completed a thesis on the topic of higher semiadditivity under the supervision of Dr. Denis-Charles Cisinski.

Chennai Mathematical Institute

Chennai, India

B.Sc. (Hons) in Mathematics and Computer Science

2017–2020

- An undergraduate course in mathematics and computer science, with a wide foundation on algebra, analysis, algorithms, the theory of computation, and programming.
- Additional final year electives focusing on algebraic topology, algebraic geometry, logic, and type theory.

Skills

Programming Python, Haskell, C, JAVA, LUA

Markup LaTeX, HTML5, XML, Markdown

Tools GNU Shell, Git, Docker, Make, Jupyter Notebooks, GNU Octave

Languages English (TOEFL 2019: 119/120), German (B2), Hindi, Tamil

Honors & Awards

2020 **CMI Medal of Excellence**, The CMI medal of excellence is awarded in recognition of outstanding performance in the National Undergraduate Programme in Mathematics and Computer Science.

2020 **Australian National University Future Research Talent Award**, The FRT is a competitive and prestigious program that attracts the very best international students from high-quality Indian institutions and provides them exposure to ANU research in the Science, Health, Medicine and Computer Science disciplines

Summer 2019 **SN Bose Scholars Program**, The Science and Engineering Board, Department of Science and Technology, Govt. of India, the Indo-U.S. Science and Technology Forum and WINStep Forward have partnered to develop a student exchange program between premier institutions in India and the United States.

2017–2020 **KVPY Fellowship**, The Kishore Vaigyanik Protsahan Yojana is a National Program of Fellowship in Basic Sciences, awarded by the Department of Science and Technology, Government of India.

Volunteering

Náboj

Universität Innsbruck

Organiser

April 2024

- Náboj is an international mathematical competition designed for teams of five high-school students that represent their schools. It is somewhat unique among math competitions, as students are encouraged to solve problems cooperatively.
  URL: https://math.naboj.org/at/de